2.—SOME ASPECTS OF SOIL MINERALOGY,

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In 1933, at the suggestion of Professor Clarke, an examination of the mineral contents of soils from Kalgoorlie, Southern Cross, and several small centres in the Goldfields of Western Australia was started, and a short account of the results was published last year (Geol. Mag. vol. LXXIII., No. 869, p. 503, 1936).

The basis of the investigation is the conception that when solid rock weathers to a soil its more resistant minerals will persist in a fragmentary condition in that soil, and should, therefore, give a definite indication of the nature of the parent material.

During the course of this investigation valuable assistance was given as follows:—First, it was made possible by the award of a Hackett Studentship by the University of Western Australia, to whom grateful acknowledgment is made. Financial assistance was later given by the Western Mining Corporation, and the Council for Scientific and Industrial Research in Melbourne, to whom my best thanks are due, as they are also to the Australian and New Zealand Passenger Conference for the award of a passage from Australia to England to enable the work to be completed at the Imperial College of Science and Technology.

I am greatly indebted to Professor E. de C. Clarke of the University of Western Australia, for the great interest he has shown at all stages in the investigation, for many helpful discussions and suggestions, and for the facilities he has made available for apparatus and field-work.

I wish also to thank the following for assistance at various stages during the investigation:—Inspectors of Mines A. W. Winzar, E. E. Brisbane, L. Gibbons (now in Papua) of Kalgoorlie for help in collecting the soil samples; the Geological Survey of Western Australia, through the courtesy of Mr. F. G. Forman, Government Geologist, for soil samples, rock specimens and for the loan of rock sections from the Survey Collection; the Western Mining Corporation for assistance in collecting soil samples from Southern Cross; Messrs. Prider and Terrill for making rock sections; Dr. C. O. G. Larcombe, Dr. B. H. Moore, and Mr. G. Spencer Compton for the information on the Kalgoorlie district; Mr. T. Blatchford, late Government Geologist, for collecting rock specimens from Southern Cross; Mr. H. Bowley, Assistant Government Mineralogist and Chemist, for help with mineral identifications; and Mrs. H. V. Rowe for transport to Leonora.

My thanks are due to Professor P. G. H. Boswell and Dr. A. Brammall at the Imperial College of Science and Technology at South Kensington, for many valuable suggestions and criticisms. Dr. Brammall gave in addition much invaluable advice on the identification of mineral grains, the description of rock sections, and expression of results.

The soils examined were collected with the view of determining the influence which the parent rock had in their formation. The majority were collected from sites where the soil profile could be seen, in order to obtain standard "heavy mineral" assemblages. ("Heavy mineral" is used for the grains which sink in bromoform of S. G. about 2.9.)

It is not proposed here to enter into a discussion of the technique employed, but to give a few features of interest from the point of view of general geology, for it is becoming increasingly evident that a study of soil mineralogy is an important branch of geology and pedology.

That most of the soils examined were directly derived from the weathering of the underlying rocks cannot be doubted from even the most casual examination of the residues. More detailed work confirms this finding, especially when not only the actual species of heavy minerals are considered, but also the *varieties* of these minerals. The importance of the recognition of varietalism of mineral species was brought to my notice by Dr. A. Brammall, who realised that correlation of soil and rock residues in any area would depend not only on the species present but also on the varieties of these species. Thus, in the Kalgoorlie soils, several types of zircon and rutile were recorded and a search of the heavy residues, obtained by crushing and separation, of rocks in the district was instituted so that the actual "home" of these species was found. *Plate I.* illustrates several types of rutile and zircon, as well as the general appearance of the heavy residues of soils obtained in this area. *Plate II.* illustrates similarly the residues of the Southern Cross soils.

At Kalgoorlie the soil residues nearly always contain a few grains of andalusite, a mineral which had not previously been recorded from this locality. Most of the soils are known to be residual, so that it is unlikely that andalusite alone would have been introduced from some outside source. Some soils occurring above greenstones at Marvel Loch, south of Southern Cross, are very similar to those at Kalgoorlie with regard to the presence of andalusite. In the neighbourhood of Marvel Loch the greenstones, partly of sedimentary and partly of igneous origin, occur as bands in beds of light-coloured meta-sedimentary rocks. These sedimentary rocks contribute the andalusite grains to the surrounding soils. The Older Greenstone series of Kalgoorlie is apparently, in some localities, interbedded with white sedimentary rocks, so that possibly the greenstones and sediments are in the same relationship to each other as are the greenstones and meta-sediments at Marvel Loch, the suggestion being strengthened by the presence of andalusite.

Another source for the andalusite at Kalgoorlie suggests itself: that it was formed by the action of intrusive porphyry on aluminous rocks. But from its widespread occurrence the first suggestion is the more likely to prove correct.

Thus a study of the soil minerals may lead to suggestions regarding further lines of investigation in the geology of any district, and brings to the fore aspects which had been overlooked or not realised previously.

Similarly any other persistent mineral such as staurolite, kyanite, sillimanite, rutile, or zircon may give a clue to the presence of rocks, which, obscured by soil, had not been known to occur in any particular area. In such investigations a study of the accessory minerals of any exposed rocks must necessarily go hand in hand with that of the heavy residues of the soils.

If the soils in a district have been formed as a result of the mixture of weathered material from several types of rock, the heavy mineral assemblages of the soils will yield the evidence whereby the extent of such mixture can be estimated, e.g., granite-greenstone parentage, or meta-sedimentary-granitic parentage. An example of such mixing, only to be expected near the contact of one type of rock with another where the land is sloping, can be cited from near Corinthian in the Southern Cross district. Two samples were collected, one from either side of a granite-greenstone contact. Both soils contained the same species of minerals in the heavy residues, but in one soil the residue was notably smaller in quantity than in the other, while the amphibole content, an important factor in the "greenstone" soils, had risen in the soil above the greenstone, but fallen in that of granitic origin, where ilmenite and limonite had increased. A word of caution must be given, however, for in dealing with soils formed from greenstones, particularly those from amphibole schists, the heavy residue yielded is very large in amount, much larger than the residue which a granite is capable of forming. Therefore the heavy residues of non-greenstone soils will be masked by the "flood" of released amphibole grains from any nearby area of soil underlain by greenstone. Where such a mixture is suspected it is advisable to remove all amphibole grains from the heavy residue in order to concentrate the minerals peculiar to soils of non-greenstone parentage.

Other features of interest revealed by a microscopic examination of soil minerals are concerned with the clay content and its nature, the colour of soils and how it is held, and the degree of rounding of the soil grains.

The clay minerals, a group of aluminous substances with a fairly wide range in chemical and optical properties, have been found to vary, as is only natural, with the type of material giving rise to the soil. Thus the clay minerals present in a soil derived from a greenstone are quite different from those yielded by a granite and often approach the chlorite group in appearance. The clay minerals of the beidellite-nontronite group (the type usually occurring in soils) are high in their base exchange capacity, and their approximate identification will give a clear indication of the base exchange capacity of the soils as a whole, a factor which is of value to the soil chemist.

Colour in soils may be due to certain minerals but is more often an expression of the influence of climatic conditions on the weathered rock material and vegetation. In some soils the colour is very loosely held, e.g., some intensely red soils from the Marvel Loch district; while in others it is most difficult to remove. When this is so, it is found to be due to a film of aluminous material coating every grain in the soil and holding the ferruginous matter. Such soils are of common occurrence at Kalgoorlie.

The roundness of sand grains is an important factor in deciding the age of some soils. It was at one time considered that the soils in such a district as Kalgoorlie owed their origin to drift by wind. Desert areas develop sand grains which have been well-rounded and are known as the "millet-seed" type. In very few soils in Western Australia have such rounded grains been found. Certainly the soils from Kalgoorlie do not fall into this group, and it is very unlikely that wind has been, in this cycle of erosion, a factor of much importance, for in its natural state, in the areas examined, the land is covered by a thick mantle of vegetation.

The following is a list of the minerals identified as grains in soils from the areas examined:—

Kalgoorlie: Magnetite, ilmenite, limonite, pyrite, leucoxene, amphibole (green and colourless), epidote, zoisite, rutile, tourmaline, sphene, zircon, mica, fuchsite, andalusite, carbonate, chlorite, garnet, gold, quartz, oligoclase, albite, orthoclase, microcline, microperthite, labradorite, micaceous and chloritic grains, clay material (beidellite-nontronite group).

Southern Cross: Magnetite, ilmenite, limonite, amphiboles (green and colourless), epidote, zoisite, rutile, tourmaline, zircon, pyrite, garnet, pyroxene, andalusite, biotite, sphene, kyanite, sillimanite, monazite, staurolite, chlorite, anatase, green spinel, quartz, orthoclase, plagioclase, oligoclase, microcline, kaolinised and chloritic or micaceous material.

Goongarrie: Magnetite, ilmenite, limonite, amphiboles, epidote, zoisite, rutile, tourmaline, zircon, sphene, garnet, biotite, quartz, albite, micaceous grains, clay material.

Comet Vale: Magnetite, ilmenite, limonite, amphiboles, epidote, zoisite, sphene, rutile, tourmaline, zircon, andalusite, quartz, orthoclase, plagioclase, microcline, clay material, micaceous grains.

Niagara: Magnetite, ilmenite, limonite, amphiboles (green, colourless, and brown), epidote, zoisite, rutile, tourmaline, zircon, sphene, garnet, muscovite, biotite, quartz, orthoclase, plagioclase, micaceous grains, clay material.

Kookynie and Tampa: Magnetite, ilmenite, limonite, amphiboles (green, colourless, and brown), epidote, zoisite, rutile, tourmaline, zircon, sphene, sericite, biotite, garnet, monazite, quartz, orthoclase, acid plagioclase, microcline, opaline silica, micaceous grains.

Yerilla: Magnetite, ilmenite, limonite, amphiboles, epidote, zoisite, rutile, tourmaline, zircon, sphene, mica, biotite, quartz, orthoclase, plagioclase, clay material, micaceous grains.

Leonora: Magnetite, ilmenite, limonite, amphiboles, epidote, zoisite, rutile, tourmaline, zircon, sphene, andalusite, mica, chlorite, pyrite, corundum, quartz, orthoclase, plagioclase, microcline, clay material, micaceous grains.

Bulong: Magnetite, ilmenite, limonite, amphiboles, epidote, zoisite, rutile, tourmaline, zircon, sphene, andalusite, garnet, kyanite, staurolite, carbonate, chlorite, mica, pyroxene, quartz, orthoclase, microcline, micaceous grains, clay material.

Kanowna: Magnetite, ilmenite, limonite, amphiboles, epidote, zoisite, rutile, tourmaline, zircon, sphene, andalusite, carbonate, kyanite, sillimanite, garnet, mica, fuchsite, quartz, orthoclase, plagioclase, clay material, micaceous grains, sericite.

The examples cited above give some indication of the scope of soil mineralogy in Western Australia. The investigator in this subject must play the part of a detective, for the soils contain numerous grains which act as clues, pointing to some parent rock or some process which is responsible for the soils as they are to-day, whether they be residual, drifted, the remains of superficial deposits since removed, or pure sands of the sand dune type. For the interpretation of the results of the examination of the minerals in soils the investigator must be well acquainted with the geology of the district in which he works, and be alive to all the possibilities revealed by what is seen under the microscope. Mere lists of mineral species from various localities give little of value without some attempt to interpret what has been seen.

It is hoped to publish later an account of the technique employed in obtaining the heavy residues, and a discussion of the methods of expressing results. Details of this investigation, which was accepted as a thesis for the degree of Doctor of Philosophy by the London University, can be obtained from the Department of Geology, University of Western Australia, and the library of the London University.

DESCRIPTIONS OF PLATES I. AND II.

Plate I.—Heavy residues from the Kalgoorlie Fine Sands.

Fig. A.—Assemblage of heavy minerals in the soil collected above the older greenstone at Somerville. No. 11178. t, tourmaline; z, zircon; zo, zoisite; a, amphibole; il, ilmenite.

× 50.

Fig. B.—Typical assemblage of heavy minerals for the Kalgoorlie soils. Soil No. 11166, collected just north of the eastern end of Trans-Australian Railway cutting. a, amphibole; an, andalusite; zo, zoisite; ru, rutile; and ilmenite. Amphibole is less abundant than in A. Many residues from the Kalgoorlie soils are similar to this.

× 50.

Figs. 1-6 indicate the varieties of rutile grains found in these soils. Nos. 1 and 2 from samples collected at the North End; No. 6, a typical mode of occurrence, fine rutile rods in a micaceous base. Sample No. 11163.

× 350.

Figs. 7-15 illustrate the varieties of zircon grains to be found in the Kalgoorlie soils. Nos. 10, 11, and 12 are from the sedimentary rocks; the remainder from various soils.

Plate II.—Heavy residues from the Southern Cross Fine Sands.

Fig. A.—Assemblage of a soil derived from greenstone; consists of a, amphibole; ilmenite, opaque. Sample 15897.

× 50.

Fig. B.—Assemblage from a granitic soil. z, zircon; il, ilmenite; and a little amphibole. Soil collected 9 miles from Southern Cross on the Turkey Hill road. Sample 12164.

× 50.

Fig. C.—Assemblage of heavy minerals from a soil derived from gneiss, Marvel Loch. an, andalusite; t, tourmaline; m, mica; s, sphene; ga, garnet. Sample No. 15899.

× 50.

Fig. D.—Assemblage of heavy minerals from a granitic or gneissic soil; collected near rock outcrops on road between Hope's Hill and Corinthian. Sample No. 12182.

× 50.

Figs. 1-8.—Various types of zircon from the Southern Cross soils.

× 300.

Figs. 9 and 10.—Monazite.

× 300.

(From brush drawings by the author.)

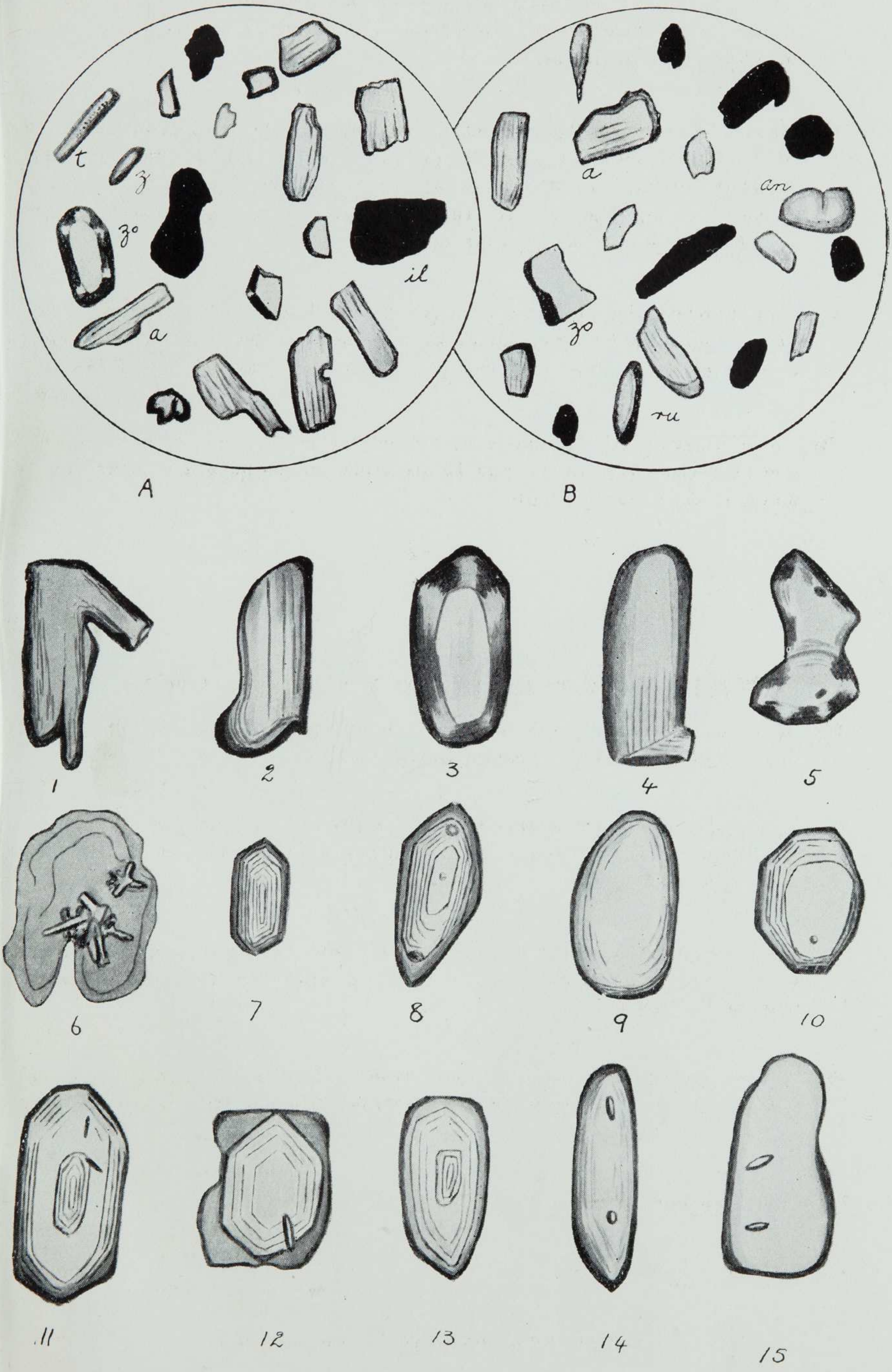

PLATE I.

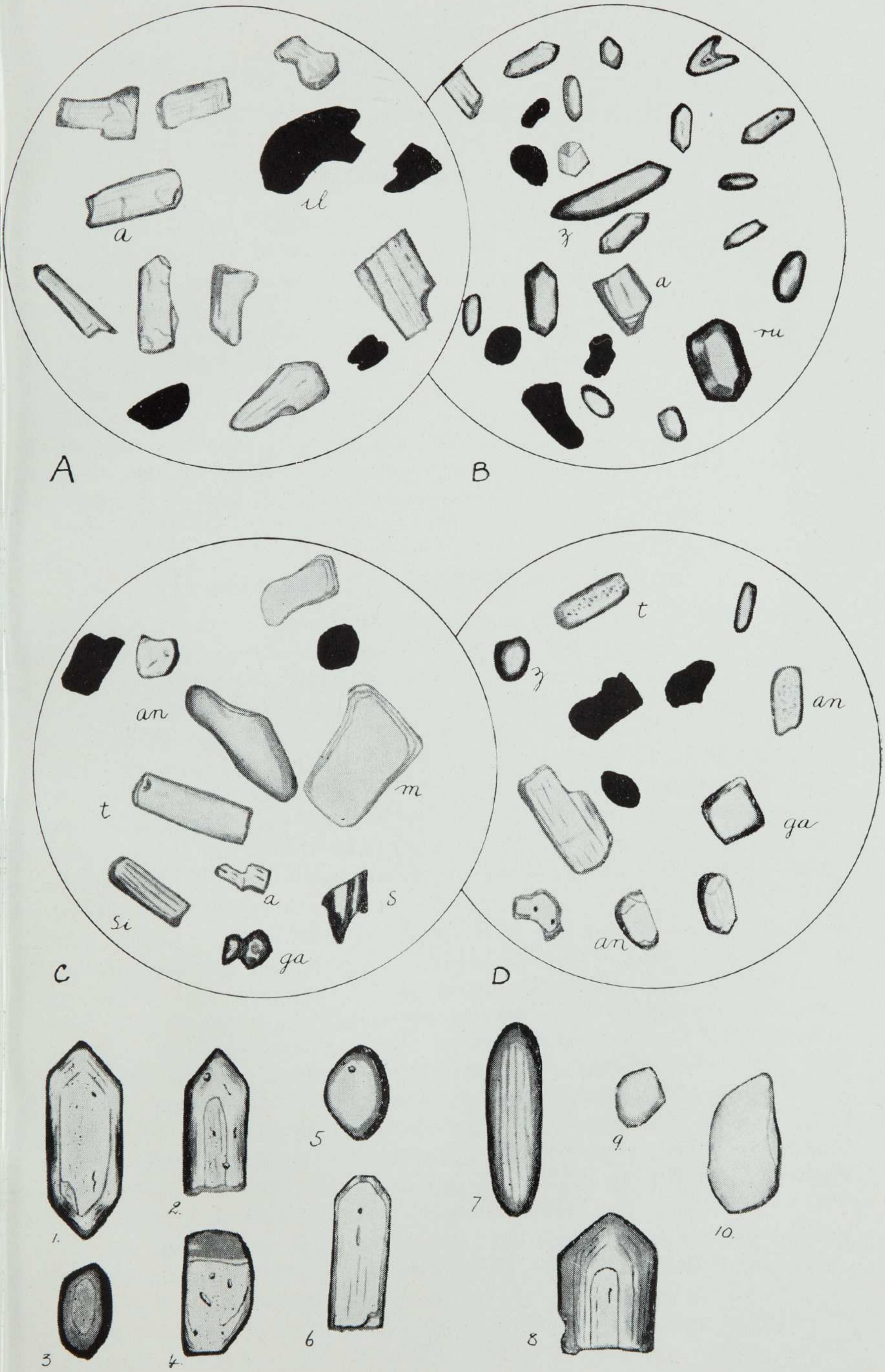

PLATE II.